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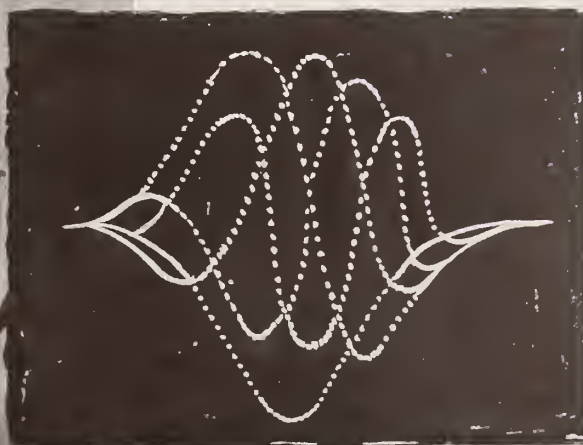
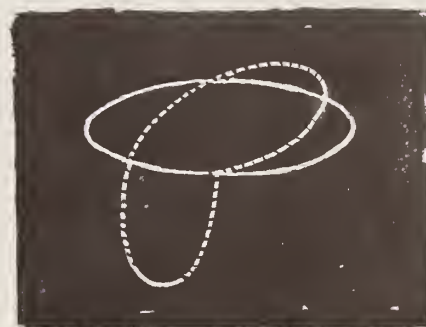
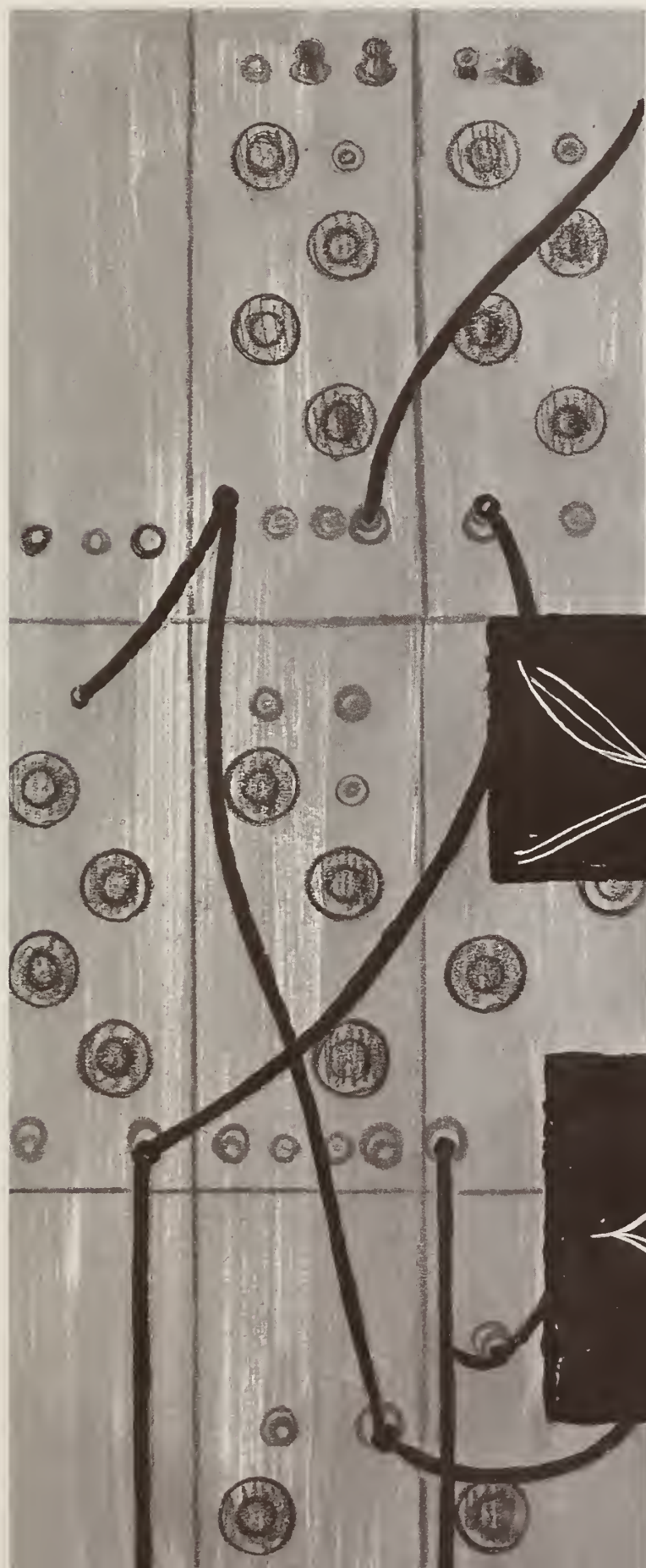
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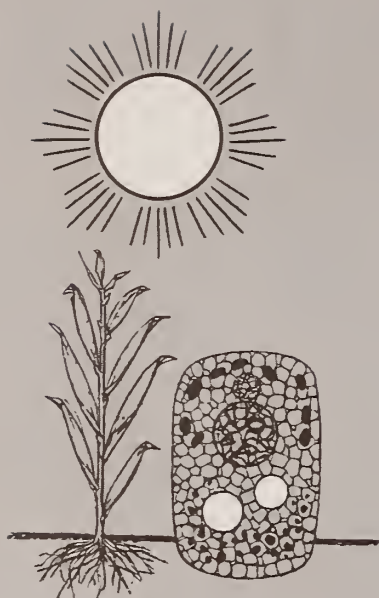
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IN AGRICULTURE
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Editorially Speaking . . .

Some readers may wonder for what reason the classic features of Goethe grace the pages of this issue of *Review*—or indeed what the association is to an article on ecosystems.

The answer lies in the quotation on the title page. Those who have the skill, patience, or imagination to come up with a meaningful translation will, we hope, feel rewarded for the effort. It expresses a universal scientific truth—the basis for the emerging discipline of ecology.

We would be delighted, of course, to claim priority for recognizing the association. But credit properly goes to United Nations Ambassador Heinrich Haymerle of Austria. The occasion was the December 3d meeting of the General Assembly where representatives of nation after nation rose to support and speak out for a Sweden-sponsored resolution calling for a worldwide conference on problems of human environment. Minutes of the meeting quite obviously reflect the pride of Ambassador Haymerle in citing the Goethe statement as being appropriate to the occasion.

If, after proper reflection and study, any reader may still find himself puzzling over a translation, the editorial office of *Review* will gladly send upon request a transcript of this section—in English, of course.

* * *

We've noted a continuing emphasis in the public press on matters relating to environmental quality. *Review* seems to be a part of this trend. Seven of our last eight issues contained articles on some phase of this topic. More are planned for future issues. One of the reasons for this emphasis, as we see it, is that related disciplines—and consequently our contributors—recognize a common problem and feel compelled to continue the dialogue in the hopes that the increasing reservoir of knowledge can somehow produce effective solutions.—W. W. K.

SYSTEMS RESEARCH IN AGRICULTURE



T. S. RONNINGEN

THE current emphasis on systems analysis in a wide area of human activity reflects not so much the inevitable popularity of a new discipline as it does the need for ways to cope with the increasing complexity of man's existence and the attendant problems brought on by science and technology.

The day of the lone scientist and his wide-ranging interests has ceased to exist. In this 20th century, we will probably never see the opportunity for such breadth of interest that could spawn a man like Leonardo da Vinci, who achieved distinction in both science and art.

Today, a scientist has a full-time job learning his own specialty. Each new generation brings still further specialization. Thus, professions such as the molecular biologist, the cryogenicist, and the servomechanism engineer have become commonplace.

But because each specialization has developed its

own tools, techniques, and language, intercommunication has become more difficult. The outgrowth of this difficulty has led to the development of hybrid sciences. One of the newest is bioengineering. These hybrid sciences, however, have solved only part of the problem. As the complexity of science activity increased, the expertise and the involvement of more and more specialists became a necessary requirement. Out of this has grown a totally new problem—one of coordination among many disciplines. As one way of achieving this coordination, science has now developed the team approach—teams of scientists and engineers pooling their knowledge and efforts to find solutions to the evermore complex problems confronting them. Thus, the concept of a systems-design team, or *systems research*, became a reality.

What Is Systems Research?

ODDLY, the systems approach to problem solving was first mentioned in the literature about 200 years ago. The French called it “systèmes”—a way of approaching and solving a problem from an un-

This article was adapted from a paper presented by the author at the Annual Staff Conference, Alabama Agricultural Experiment Station, Auburn, Alabama, December 12, 1968.

confined viewpoint. But unfortunately the systems approach languished in an unrefined state until World War II when it was first put to practical use by the military agencies.

Because of the particular problems facing the military, together with the tools and methodology employed, the term *systems analysis*, first became associated with electronic computers, large-scale mathematical models, multi-disciplinary teams, and cost effectiveness. Although it is true that such factors often are essential elements in systems analysis, they need not be. As a matter of fact you can conduct a good systems analysis by yourself, doing simple arithmetic on a scratch pad.

Systems research, which this paper emphasizes, has all the characteristics of *systems analysis*, except that it has one important addition—that of developing a new system not known before or implementing operations never before performed.

C. J. Hitch has described *systems analysis* as an approach which defines and attacks a problem in terms of five essential elements:

An *objective* or a number of objectives.

Alternative means (or “*systems*”) by which the objective may be accomplished.

The “*costs*” or resources required by each system.

A mathematical or logical *model* or models; that is, a set of relationships among the objectives, the alternative means of achieving them, the environment, and the resources.

A *criterion* for choosing the preferred alternative. The criterion usually relates the objectives and the costs in some manner, for example, by maximizing the achievement of objectives for some assumed or given budget.¹

For *systems research*, therefore, we should add a sixth element—the concept of new alternatives to reflect the research aspect.

To put this in simpler language, we might say that systems research permits a whole view of a problem, and—provided the inputs are sound—it provides the most logical solution or solutions. Systems research, therefore, suggests a commonsense approach to problem solving. However, we must be sure that we are addressing ourselves to the right problem.

Kinds of Systems Research

ONE of the favorable characteristics of the systems approach to problem solving is the versatility it offers. Because of the wide range of available applications, a researcher can readily tell whether the systems approach would be feasible simply by identifying the elements of the problem to determine if system behavior can be predicted by applying logic to some fundamental postulates. The practicability of this technique has already been demonstrated in five different kinds of systems research in agriculture.

Some of these and similar applications may be better classified under operations research. Many uses will have characteristics of both operations and systems research. This paper puts greater stress on seeking new combinations of activity for the betterment of segments of American agriculture under study.

A New Development in an Established System—When an established system faces possible change because of a new technological development—in other words, introduction of a known variable—then a systems research approach can be called upon to determine how that variable will affect other variables. In such situations, new subsystems often need to be designed.

A typical example of a recent development of this type is the mechanical tobacco-leaf harvester. Here, it was readily apparent that the change from hand harvest to machine harvesting would in turn affect other variables: the drying subsystem, grade standards, and allotment laws to permit economy of scale in operation.

Change in Input Relationships—When the importation of braceros from Mexico to California was drastically reduced, the fruit and vegetable enterprises in that State were faced with a marked change in a very sensitive input—the availability and cost of labor. Immediately, the affected industries pressured the California Station to alleviate their difficulties through improved mechanization.

In tomato harvesting, for example, the most immediate solution would be to substitute directly a mechanical harvester for hand picking. The California Station, however, has not stopped there. They are developing a tomato plant and a machine with maximum cross compatibility in a research-develop-

¹ From an article in *Analysis for Military Decisions*, Ed: E. S. Quade, Rand, McNally & Co., Chicago, 1964.

mental process they call bioengineering. The plant they seek has cylindrical rather than round fruit so it bruises less on the conveyor belt. The tomatoes ripen more uniformly and hang near the top of the plant.

Appearance of Negative Effects—The agricultural sciences are keenly aware of a new negative effect that only a decade or so ago was the least of our concern—environmental pollution. We have a dual concern here: pollution which agriculture itself produces, and non-agricultural pollution which adversely affects crop production. Opportunities exist for both systems analysis and systems research, although we are handicapped in some cases because of the inadequacy of data describing the polluted environment. A joint USDA-State station task force has strongly recommended adoption of a systems analysis approach in solving several of our more serious pollution problems.²

Reducing Production Costs—A research director of a large eastern cooperative said recently that reduction in labor requirements per dairy cow to 20 hours annually (average of 80 hours now) was possible and would help the dairy business greatly.

What system or systems of feed production and handling, herd management, and waste disposal would result in such sizable reduction in input? Could research accomplish this aim merely by improving the cafeteria display of improved practices? I would doubt it. The problem is well-suited to the newer concept of systems research.

Another classic example of a cost-reduction problem suited to systems research concerns cotton. It is heartening to note that the Congress recognizes cost reduction as a means of enabling cotton to compete more successfully on world markets. Lower costs would mean lower prices without damaging loss in profits to the farmer.

Application to Non-agricultural Problems—One of the finest examples of the kinds of systems research in which agriculture can participate is that wherein we use our resources and know-how to help solve problems not actually related to agriculture. Such research is already beginning. For example, both the Illinois and Pennsylvania Stations are seeking ways to make the land and its plants a living

filter for processed sewage effluent. This systems research has a dual purpose—not only getting rid of the effluent, but also putting it to some practical use during the elimination process.

Another excellent example is the sociological research aimed at easing the problems in big city ghettos by eliminating some of the rural conditions that foster continued growth of the ghetto. People are leaving depressed rural communities to seek city jobs for which they are not qualified. Thus, rural-urban social and economic problems become intermingled. A number of states are already active in this kind of systems research, but it definitely needs to be expanded and strengthened.

Undoubtedly there are other kinds of systems research. Among the various agricultural disciplines, the engineers are perhaps most aware of the inherent possibilities. Some of these were discussed in a recent ASAE publication and would merit careful reading.³

Lost Opportunities

THE successes achieved so far in applying systems research to agriculture have enabled us to improve our hindsight on problems that crept up on us before we were even aware that they would ever exist. In other words, some of the problems we face today have grown to their present gigantic proportions because at some point of time in the past we couldn't see the forest for the trees. We might call these lost opportunities—lost because we couldn't or didn't apply the systems approach at the crucial time when it would have brought us the greatest return.

Because of these lost opportunities, the hindsight now available to us may, hopefully, open our eyes to potential problems that even now may be imminent. One single discipline can never hope to envision what its discoveries and developments may lead to in the future. Only a coordinated, multidisciplinary approach—relying heavily on all the tools, methodology, and resources that systems research provides—can foretell problems and provide appropriate ways and means to either avoid them

² "A National Program of Research for Environmental Quality—Pollution in Relation to Agriculture," U.S. Dept. of Agriculture, Wash., D.C., Sept. 1968.

³ "Transactions of the American Society of Agricultural Engineers," Vol. 10, No. 3, 1967.

or to prevent them from becoming insurmountable.

A typical lost opportunity concerns agricultural wastes. Good aggressive systems research 10 or 15 years ago should have predicted the critical problems we must presently face in the management of animal wastes. The trend had already begun in the concentration of livestock production units in ever-increasing numbers on relatively small acreages. We should have been able to predict that massive quantities of manure would have to be dealt with—that chemical fertilizers would be cheaper than the nutrients in the manure—that land areas associated with the livestock production units would be too small to decompose the organic wastes. In short, that research was needed *then* to find alternate solutions to the problem of animal waste management.

Another lost opportunity concerns wheat production. Why did U.S. plant breeders devote three-quarters of a century to the development of tall-strawed wheat varieties? Did they not foresee the potential inputs that would revolutionize wheat production—more abundant fertilizers, improved machinery, greater consumer demand? Japan, for instance, had developed good semi-dwarf wheat varieties by the early 1930's. But then we must realize that Japan was forced into intensive cultivation and fertilization practices long before the United States was. In other words, population pressures, burgeoning food demands, and limited land resources helped to show Japanese wheat breeders that a dwarf prolific line was an economic necessity.

The agricultural disciplines have passed up other opportunities to gear their research to future needs. Not all of them, fortunately, were major ones. We are just beginning to dig ourselves out of the "silent spring" crisis of a decade or so ago, when our aim was to "kill the bug" without thought of ecological implications. Perhaps we can take some measure of satisfaction from the realization that the systems approach may enable agricultural scientists to orient their work to the future rather than devising corrective measures dictated by the present or forced upon them by the oversights of the past.

Potential for Adoption of Improved Systems

IT might be inferred from these comments on so-called lost opportunities that agricultural science

is laboring under the handicap of inaccurate definition of goals. To the contrary, the multidisciplinary approach, or systems analysis, is definitely not a panacea to be applied indiscriminately to every quarter. Much good research can still be carried out in the traditional manner.

Consider applied or mission-oriented research, for example. Whenever there is specific goal to attain or an obstacle to overcome, research policy should emphasize alternatives.

As stated earlier, it is important to ask the right question in approaching a research problem. One of the reasons for doing this is to avoid those which may give a quick result and concentrate instead on those which are really worthwhile tackling. As Paul Weiss has stated: "The primary aim of research must not just be more facts and more facts, but more facts of strategic value."⁴ He implied here, of course, the need for deeper insight that may lead to the linking of previously unrelated facts and ideas.

Those scientists participating in systems research on a multidisciplinary basis will need to remember the integral worth of each other's discipline. This is not an occasion to establish a "pecking order" or to assign greater or lesser importance to the potential contribution each can make. Former Secretary of Health, Education, and Welfare John Gardner expressed it well when he wrote:

"An excellent plumber is infinitely more admirable than an incompetent philosopher. The society which scorns excellence in plumbing because plumbing is a humble activity and tolerates shoddiness in philosophy because it is an exalted activity will have neither good plumbing nor good philosophy. Neither its pipes nor its theories will hold water."⁵

Of all the potentials for the use of systems research in agriculture, one of the most promising, it seems to me, is the area of farm management. We hear a lot of discussion today about the relative merits of the family farm and the corporation farm. What is the dominant pattern likely to be in another generation or so? Should the agricultural sciences take steps to enhance the position of one over the other? Or should we, through systems research, find ways to stabilize the advantages of

⁴ Weiss, P., *Science*, 101:101, 1945.

⁵ Quoted by Harold Howe in *Civil Service Journal* 9:1, 1968.

each so that unforeseen or inherent weaknesses would not lead to the total decline of either one?

In my opinion, many family farms suffer from "management gap." Systems research, with the necessary extension inputs, offers opportunity to prepackage the latest know-how for direct use by farmers. Cornell University is currently doing this with a number of farms. But it may not be enough for a farmer to occasionally slip in an improved practice to his existing system. In other words, the systems approach may give the family farmer management advantages comparable to the "packages" guidance a retail outlet owner receives from a parent company.

Many farmers admit that they don't farm nearly as well as they could. They are aware of new techniques available that would materially improve their economic position. Yet the typical pattern is to wait until "community innovators" demonstrate that something is feasible. Thus, farm practice generally lags behind farm science much more than it should. Closing this source-to-adoption gap would seem to be a tailormade problem for systems research.

Here is another interesting potential for systems research in farm management: identifying the most useful farming mix in a community made up of part-time and full-time farmers. Since part-time farmers generally owe first allegiance to their job in town, the situation suggests an opportunity for an extensive farming enterprise on a community-wide basis. Can full-time farmers utilize extensive operations which may be performed best by their part-time farming neighbors (feed production, establishment of wildlife cover, maintenance of breeding animals, etc.) and concentrate only or mostly on intensive operations needed to maximize their income? If this scheme is not feasible now, perhaps it will be later when the proportion of part-time farmers has increased.

Obviously, there are other examples of potential application. Consider, for instance, cotton production and efficiency of irrigation. Cotton lost its position as the No. 1 fiber—not because of its inferiority to manmade fibers, but because of the economic organization which didn't allow it to get a fair break in modern competition.⁶ There are dozens of pos-

sibilities for using the systems analysis approach in attacking problems related to the three essential factors in the fiber situation: price, research, and competition. Consider where cotton might be today if 30 years ago it had had the benefit of a research and promotion program similar to that of manmade fibers—the same farseeing programs that brought synthetic fibers to their present prominent position. Or, where would cotton be today if its use in blends had been researched earlier and more strongly? The opportunity may still be there, although somewhere along the line we missed an earlier one.

The growing scarcity of irrigation water and the rising costs of applying it are creating a situation that is admirably suited to systems analysis. Agriculturists would do well to study the approach being used in the Colorado River Basin Project in which every conceivable water use—direct and indirect—was considered as an essential input and in turn objectively evaluated—not from the viewpoint of agriculture, or of industry, or aesthetic or recreational values, but from the viewpoint of the ultimate good to all interests.

Other potentials for improving systems might also be identified. Each researcher, being aware of the particular discipline-oriented problems he faces, could probably pinpoint specific areas where the thinking of the generalist needs to be introduced.

Conclusions

MOST certainly, systems research is much more feasible today than it formerly was. High speed computers open up vast possibilities to analyze masses of data in determining the best alternatives in problem solving. The scope of available data, also, has broadened. An agricultural scientist in this generation, for example, has at his fingertips much more ancillary information than his counterpart of another era: highly detailed weather data, soils data, crop records, animal performance records, and social and economic statistical data, to name a few. Actually, the very existence of this ancillary information seems to make the systems analysis approach to problem solving more imperative than ever—particularly when we consider that science today is characterized by specialization. Moreover, scientists now have a variety of sophisticated tools that are especially adapted to large-scale system design.

⁶ Horne, M. K. Jr., "Situation Paper on Cotton," In: *Synthetics and Substitutes for Agricultural Commodities*, Pub. No. 1, Univ. of Florida, 1966.

Queueing theory, game theory, linear programming, simulation, cybernetics, and group dynamics—all these and more help to broaden the range of usefulness of systems research.

Systems analysis can be useful in several ways. It can help either the administrator, the researcher, or the user, through the development of more information on which to base judgment. The objectives of each, together with the constraints in the problem, may indicate that three sub-systems are required. Systems analysis brings relevant issues out into the open—perhaps even those which otherwise would not have been recognized. And third, it can reduce reliance on judgment; in other words, it makes the application of judgment a more orderly process.

Scientists can, however, encounter a number of pitfalls in using the systems approach. One of the most serious is the failure to differentiate between a system-design endeavor and a pure research endeavor. If some of the components in the mathematical model have not been thoroughly explored by conventional research, the systems-design team runs the risk of converting questionable inputs into questionable outputs. Skillfully designed models become little more than mathematical toys, and the standard dictum GIGO (garbage in, garbage out) would apply. Another risk—particularly when the proposed system is extremely complicated and requires the use of highly sophisticated mathematical models—is that attention can be diverted from the substance of the problem to the pure mechanics of the analysis. Systems analysts should never lose sight of their real world problem; their actions should be problem-oriented and problem-motivated—not motivated wholly by curiosity.

These cautions are necessary only for those who will not challenge “hard copy”—whatever the source. A computer simply has a larger flow in GIGO than an adding machine tape. Statistics can provide a “tool,” but if the sample results are too scattered or there is too much unexplained variability, then the analyst probably didn’t understand the problem or its magnitude.

Even though good systems analysis can help offset the constraints of narrow vision and narrow specialization, there is always the danger of ap-

proaching a problem from a confined viewpoint. Jensen of Cornell states that because of this typical approach to problem solving, we tend to accept the problem as it exists and work directly toward a solution. He points out that this narrow approach may lead to a workable but still unsatisfactory solution, as in the use of alternate field strips in hybrid wheat production. Hence, the need exists for research on a basic problem—inefficient land use in the production of hybrid seed.⁷

As agriculture attempts to broaden the usefulness and application of systems analysis and systems research, the most serious obstacle may not be the problem itself but lack of understanding and appreciation of the concept by management. A number of factors contribute to this situation. Our organizational and administrative setup is still geared largely to the concept of pure science in which each discipline continues to maintain its own ivory tower. Our educational process has not produced enough generalists. Our present legislative attitudes and tightening budgets would seem to demand a shortening of the interval between the recognition of a problem and the development and application of the proper technology for the ultimate user or consumer.

Hopefully, we might speed the process of effecting the needed changes by providing the kind of environment whereby our combined technical ingenuities will approach problem solving with an eye to the future. True, we are making some progress toward that end in the Long Range Study.⁸ Yet, there are times when we seem to be concentrating too much on the probable need for scientist-man-years rather than on ways to minimize or avoid future problems, the signs of which may now be only partly identifiable.

Someone has said that systems research works best for an aggressive master. I believe we have both the climate and the human resources in agriculture to fill that role. Certainly, the concept of systems research is well-founded, and its efficacy has been amply proved. Its wider adoption in agriculture, therefore, needs to be properly encouraged.

⁷ N. F. Jensen. *Science*. 157:1405. 1967.

⁸ “A National Program of Research for Agriculture,” Report of a study sponsored by the National Association of State Universities and Land-Grant Colleges and the U.S. Department of Agriculture, October 1966.



TROPICAL AND SUB-TROPICAL GRASSLAND RESEARCH

E. M. HUTTON

ALTHOUGH some of the research problems facing agronomists working with tropical and subtropical forages are essentially the same as those in temperate regions of the world, the very nature of tropical soils and climate introduces either totally new problems or variations of those found elsewhere. The needs and habits of the grazing animals, likewise, must be considered as unique factors in the tropics.¹

As pointed out in recent world surveys, it is in the developing countries of the tropics where population growth is most rapid and deficiencies of dietary energy and protein are most acute. Major

advances in production with food grains—such as the breeding of new high-yielding rice varieties at the International Rice Research Institute—may quite likely help to overcome deficiencies in energy foods. Similar advances on tropical grassland research also show much promise in helping to overcome animal protein deficiencies. As a matter of fact, if results of recent research with tropical pastures in Northern Australia, Hawaii, Puerto Rico, Jamaica, and southern Florida were widely and diligently applied, the ever present and serious deficiency of vital animal protein in the tropics could be reduced significantly. But yet many important problems in tropical pasture research remain unsolved.

Sixty percent of the world's cattle and 50 percent of the sheep and goats are in the tropics. Considerable potential exists for increased animal produc-

¹ The tropics are mainly the lands between latitudes 30°N and 30°S and constitute about 40 percent of the area of the world. Although most people consider the tropics to be constantly moist, humid areas with lush vegetation, three quarters is "dry tropics" where periods of moisture stress occur during the year.

tion, as it has been calculated that 10 percent of the tropics is cropped, 20 percent is pasture, 35 percent is forest, and a third is wasteland. Because of the mediocre quality of tropical pastures, milk yields are low and carcass weights of cattle are often less than half those obtained in the United States and Europe. Forest areas and wasteland are commonly in hilly country, and sporadic attempts to crop them have resulted in soil erosion. In contrast, immense benefits can be expected from development of idle uplands and current pasture areas by using our new knowledge of the tropical pasture ecosystem.

Tropical legumes should be the focal point of development, because they provide the cheapest source of protein for the animal and the cheapest source of nitrogen for associate grass (23).² But before extensive areas of tropical pastures are sown in a new region, it is necessary to determine the soil nutrient deficiencies, the legumes and grasses capable of producing pastures there, and the effects of rhizobium inoculation on legume growth (42). Correction by appropriate fertilization of any deficiencies in phosphorus, sulphur, potassium, or minor elements like molybdenum and copper is essential for healthy growth of legume-based pastures and of the grazing animal.

The Important Legumes

ALL the successful tropical pasture legumes have come from Central and South America and Africa, and with few exceptions are strongly perennial. The accidentally introduced Townsville lucerne (*Stylosanthes humilis*) is the only important annual and has become the main pioneer legume in northern Australia following demonstration of its ability to markedly increase cattle live-weight gains and year-round carrying capacity of pastures (34), (41). It thrives in the Northern Territory above the 30-inch isohyet and in Queensland between the 22- and 60-inch isohyets, particularly from the central area north. Siratro, which was bred from two Mexican ecotypes of *Phaseolus atropurpureus* (22) has become important over a wide range of conditions. It is drought-resistant, and in northern Australia grows in dry sub-coastal areas as well as along the

moister coast. In South Florida, Kretschmer (26, 27) has had promising results with both Townsville lucerne and Siratro in cattle pastures.

Research by the Hawaii Agricultural Experiment Station (43) showed the value of *Desmodium intortum* and the three *Leucaena glauca* (now *L. leucocephala*) as forage for cattle. This led to the selection and commercialization of Greenleaf Desmodium (*D. intortum*) and Peru Leucaena by the C.S.I.R.O. Division of Tropical Pastures. Both of these thrive above the 35-inch isohyet in eastern Australia and the 45 inch in the Northern Territory. Silverleaf Desmodium (*D. uncinatum*) from Brazil and Miles Lotononis (*L. bainesii*) from the Transvaal are finding a place in moist subtropical coastal areas and were also commercialized as a result of work by the Division of Tropical Pastures (9, 10).

The importance of Glycine (*G. javanica*) on better coastal soils was shown by the Queensland Department of Primary Industries which developed the cultivar Tinaroo. Two other Glycine cultivars, Cooper and Clarence selected by the Division of Tropical Pastures and New South Wales Department of Agriculture, respectively, are increasing the range of soils over which this legume can be grown. It is of interest that large areas of Glycine are now being planted on kraznozems in some areas of Brazil. Stylo (*Stylosanthes guyanensis*), Centro (*Centrosema pubescens*) and Puero (*Pueraria phaseoloides*) have been important on the wet tropical coast of north Queensland for over 25 years (40).

The tall growing and bulky Rongai Dolichos (*D. lab lab*), a biennial collected in Kenya, is popular in rotations and as a preparation for permanent pasture. Several other Dolichos species including the perennial Archer axillaris (*D. axillaris*) are finding a place in Queensland pastures. Dalrymple Vigna (*V. luteola*) is a promising biennial for moderately saline soils and poorly drained situations. No doubt the range of valuable tropical legumes will be increased by further research and plant introduction. Now that Hegarty and Pound (19) have determined that the hepatotoxin in *Indigofera spicata* is the new amino-acid indospicine, the potential of this legume shown by the Hawaiian Agricultural Experiment Station may be realized by the breeding of non-toxic lines.

The temperate legumes alfalfa (*Medicago sativa*)

² Italic numbers in parentheses refer to Literature Cited, p. 16.

and white clover (*Trifolium repens*) also have an important role in the sub-tropics and high altitude regions of the tropics. Where frosts occur in the dry season, as in Queensland south of the Tropic of Capricorn, these legumes will be increasingly used in association with the tropical types.

Characteristics of Tropical Legumes

EACH of the legumes developed in Queensland was selected for responsiveness to superphosphate and persistence under grazing in one or several of the ecological zones. Because of their adaptability they are finding ready acceptance in northern Australia and are being used increasingly in overseas countries. A number have a short history as pasture plants and most possess undesirable "wild" characters which will eventually be modified by breeding. Substantial quantities of commercial seed of these legumes have been available only recently. Research is still needed on harvesting techniques and factors responsible for seed set, since some seed yields are too low.

All the tropical legumes thrive on fertile soils. With the exception of Glycine, they also grow well on the large areas of somewhat acid solodic and podsolic soils in northern Australia low in calcium—provided the usually deficient phosphorus, sulphur, and molybdenum are supplied. This characteristic is due to their superior ability compared with temperates to extract calcium from the soil and thus nodulate at low calcium levels (2). Again with the exception of Glycine, the tropicals are mostly tolerant of the excess manganese and aluminium often present in poor acid soils. Most tropical legumes nodulate freely when supplied with the right alkali-producing *Rhizobium* (36) but some, like Greenleaf Desmodium and Glycine, nodulate slowly and establishment is delayed. Genetic variation in nodulating ability was found in Centro by Bowen and Kennedy (6). Miles Lotononis is unusual because it has extreme strain specificity and nodulates only with a *Rhizobium* that forms red colonies in culture (35).

Research has shown that the ability of tropical legumes to fix nitrogen is almost as good as that of white clover under optimum conditions (18). Jones *et al.* (25) found that the increase in nitrogen yield of pasture from inclusion of tropical legumes was positively correlated with legume yield. Breeding

more vigorous tropical legumes would increase legume dry matter and protein in the pasture and overall nitrogen yield but may not fully meet the nitrogen demands of the rapidly growing tropical grasses. However, pasture feeding value would be raised because for most of the season, tropical legumes gives a higher animal intake of digestible energy and protein than tropical grasses (31). Fortunately tropical legumes appear to be quite low in oestrogens, and, with the exception of Rongai Dolichos, they have not been known to cause bloat.

When subjected to frost as in the Australian sub-tropics, the above ground growth of all the tropicals except Miles Lotononis is killed. There are some differences in tolerance. For example, foliage of Townsville lucerne, *Leucaena*, and Siratro is usually more frost susceptible than that of Glycine and Greenleaf Desmodium. The crowns and root systems of the perennials regenerate unless frosting is intense and repeated. The main legumes are tolerant or resistant to root-knot nematode, and with the exception of the Desmodiums and Miles Lotononis have field resistance to the disease legume "little leaf," recently shown due to a *Mycoplasma* by Bowyer.³ Mosaic virus diseases such as yellow bean mosaic and alfalfa mosaic have appeared at low frequency in several legumes but give no indication at present of becoming epidemic. In wet tropical areas defoliation by fungi like *Rhizoctonia solani* becomes limiting in some legumes including Siratro. *Amnemos* and other indigenous root-eating weevils have caused severe damage to the Desmodiums and Glycine and at times to other legumes in parts of the Australian tropics, particularly in dry seasons.

Adaptation of Legumes to Pastures

THE annual, Townsville lucerne, has thin fibrous stems and narrow, pointed leaves and grows erect to two feet or is prostrate depending on soil fertility, grazing pressure, and ecotype. Its success comes from its adaptability, good seed production—as high as 1,000 lb per acre—ease of re-establishment, and tolerance to grazing due to moderate palatability. Ability to thrive on poor soils results from a capacity to absorb greater quantities of phosphorus per unit weight of root tissue per unit time than

³ Personal communication from J. W. Bowyer, Department of Microbiology, University of Queensland.

other species at both low and high phosphorus concentrations (1). Because of its intolerance to shading, it does best in pastures in which grass growth is controlled by grazing. Improvement in Townsville lucerne is being sought not only by selection (12) but also by intercrossing with perennials including *S. guyanensis* and *S. hamata*.

The perennial Siratro has leaflets 5 to 8 cm long and deeply penetrating swollen roots. Trailing stems root at random only when the soil is moist for an extended period. It is compatible with a range of bunch grasses, and its twining habit allows it to reach the light in dense lightly grazed pastures. Actual seed yields are high, but sequential ripening and shattering of pods reduces commercial seed yields to 100 to 150 lb per acre. It establishes readily on new land if hardseededness is reduced by mechanical scarification. Because of intolerance to temperatures below 70°F, growth from autumn to spring is restricted in the area south of the Tropic of Capricorn in Queensland. The current C.S.I.R.O. breeding program involves derivatives of Siratro and ecotypes from an extensive Central American collection of *P. atropurpureus* and aims to correct the deficiencies in Siratro. Results indicate that it will be possible to combine high yield, cold tolerance, a minimum of pod shattering, and resistance to *Rhizoctonia solani*.

The Desmodiums are prostrate vigorous perennials, and the leaves are readily eaten by cattle in spite of a relatively high tannin content. Greenleaf is hardier and higher yielding than Silverleaf, but is slower establishing. The Desmodiums are both self- and cross-pollinated and the flowers have to "trip" to set seed, causing some problems to the plant breeder. The C.S.I.R.O. program is concentrating on Greenleaf to improve its low seed yield, poor resistance to legume "little leaf," and slow nodulation and field establishment. The useful genes in *D. sandwicense* and *D. uncinatum* are not being neglected; crosses between these and *D. intortum* have been made (24).

Leucaena is actually a tree, but will become a shrub under grazing. It is deep-rooted, drought-resistant, and adapted to well-drained soils. Seeds are sown in rows 10 feet apart, cultivated until established, and then inter-planted with a grass like Pangola (*Digitaria decumbens*) or Guinea (*Panicum maximum*). This method gives a highly pro-



Close up of Siratro (*Phaseolus atropurpureus*) bred by C.S.I.R.O., Division of Tropical Pastures, growing at Samford Pasture Research Station near Brisbane, Q.

ductive, two-level pasture. Leucaena herbage contains 4 percent nitrogen as protein, a higher level than most tropicals, but has an additional 0.5 percent nitrogen as mimosine—an undesirable depressant of cell division (17). Wool shedding occurs in sheep fed Leucaena, and there has been concern that it would affect cattle reproduction despite results of the Hawaiian Agricultural Experiment Station (3).

In a recent Queensland experiment, dairy heifers fed only Leucaena all conceived and had normal pregnancies. The bovine rumen degrades mimosine, so there is no urgency to breed mimosine-free lines.

Because cattle eat only leaves and twigs 0.25 inch or less in diameter, we are breeding lines with a high proportion of leaf and short bushy habit to keep herbage within reach.

Miles Lotononis is a slender, procumbent, stoloniferous perennial rooting at the nodes only on permeable soils. Seed is very small, half the size of white clover, and early establishment is slow; but it soon develops a dense stand under the right conditions. Poor persistence under grazing on soils which set hard is due to failure of stoloniferous roots to develop. It is the only tropical legume highly compatible with the aggressive Pangola grass.

Glycine is a trailing, twining perennial not unlike Siratro, and roots along stems in contact with the soil. Intolerance of Glycine to acid solodic and podsollic soils may be due to a high-lime requirement or sensitivity to excess aluminum or manganese. Breeding programs are aiming to develop lines adapted to a range of soils and with quicker nodulation and establishment. Wutoh, *et al* (44) have shown that early flowering, high yield, and good stolon development can be combined—which is of particular advantage when breeding for drier environments.

The perennials Stylo, Centro, and Puero are intolerant of cooler sub-tropical conditions, but are dependable legumes for the wetter, more tropical coast of some two million acres north of the Tropic in Australia. Stylo and Centro are indigenous in South America and Puero in Indonesia; all have been grown over the years in most tropical countries. Difficulties have often been encountered, particularly with Centro and Puero, in maintaining them with associate grasses like Guinea under relatively high grazing pressure. This is usually due to lack of soil nutrients such as phosphorous, sulphur, molybdenum, and copper. In Australia, the tall-growing Stylo, although phosphate responsive, is tolerant of low soil fertility and has some tolerance to poor drainage and dryness. Centro is creeping and twining and will form a dense persistent pasture. Puero, a vigorous climber, has long runners and large leaves, is very palatable, and may not persist under heavy grazing. Both need 50 inches or more annual rainfall to flourish and Centro has been shown to markedly affect soil fertility in Nigeria (33) and the Australian tropics (8).

In cooler parts of the tropics, alfalfa and white clover can provide valuable high protein herbage

in the dry season when frosts and cold weather limit growth and feeding value of tropical species. Commercial Hunter River alfalfa persists only a few years in the Australian subtropics because of rotting of ageing crowns in the hot, moist summer. The creeping-rooted alfalfa Rambler, bred by Heinrichs (20) has been intercrossed with Hunter River and introduced alfalfas. In the progenies there was a high correlation between creeping-rootedness and both survival and yield (7). Bred lines of grazing alfalfa which persist in our subtropics are being selected. In these, moribund crowns are replaced by young vigorous sub-surface crowns from creeping roots.

White clover is mainly annual in tropical north-eastern Australia. Here, a small-leaved, low-yielding type with spring growth is naturalized in favorable areas. Introduction of Ladino, Louisiana, or other cultivars and using molybdenized superphosphate results in intercrossing with the naturalized type and quick development of better adapted, vigorous strains with a longer growing season. *T. semipilosum*, or Kenya White clover, has potential in white clover areas because of its drought resistance, due to a deep root system, and superior yields to white clover in the winter to early summer period.

The Important Grasses

THERE is a wealth of tropical grasses, and, with few exceptions like the Paspalums from South America and *Sorghum almum* from Argentina, they are indigenous to Africa. Those grasses important in the moister areas include the taller varieties of Guinea (*Panicum maximum*), Brachiaria (*B. mutica* para grass, *B. brizantha*, *B. decumbens*, *B. ruziziensis*), Elephant (*Pennisetum purpureum*), Kikuyu (*P. clandestinum*), Molasses (*Melinis minutiflora*), Pangola, *Digitaria smutsii*, African Star (*Cynodon plectostachyus*), Paspalums (*P. dilatatum*, *P. notatum*, *P. plicatulum*, *P. commersonii*), and Setarias (*S. sphacelata* complex). There is not as wide a range of grasses available for the extensive dried areas in the tropics and subtropics as in Australia and Africa. The best drought-resistant grasses at present include Green Panic (*P. maximum* var. *trichoglume*), and varieties of *P. coloratum*, buffel (*Cenchrus ciliaris*), Rhodes (*Chloris gayana*), *Sorghum almum*, and *Urochloa mosambi-*



Yearling Droughtmaster cattle (derived from Shorthorn—Brahman cross) grazing on Spear grass—Townsville lucerne pasture at C.S.I.R.O. Lansdown Pasture Research Station.

censis. The somewhat despised Spear grass (*Heteropogon contortus*) indigenous in northern Australia and India is now regarded with favor as an associate for Townsville lucerne as a result of research in Central Queensland (41).

Dry matter production is not a problem in tropical grasses because they grow very rapidly under hot and moist conditions and when soil nitrogen, phosphorus, and potassium are sufficient. Some grasses—such as the tall growing Hamil (*P. maximum*)—have an outstandingly high photosynthetic efficiency (28). A major deficiency in tropical grasses, with the exception of species like Pangola and Kikuyu, is the quick decline with increasing maturity in digestibility and animal intake (30), due to a rapid increase in crude fibre and shortage of digestible energy (32). An additional complication is the marked drop in protein level with maturity. Thus, most tropical grasses have a lower efficiency of conversion into milk and meat than temperate grasses in which the decline in feeding value is not so marked. Where nitrogen is used in tropical areas, a high and economic return of digestible nutrients and animal products will only be obtained with

Pangola and Kikuyu or grasses of similar feeding value.

Tropical grasses are more tolerant of unfavorable soil than of unfavorable climate. For instance although Kikuyu does best on kraznozems, it needs moist environments, while buffel and *Sorghum almum* thrive only in drier environments on most permeable soils. Response of the different grasses to each of the major elements—nitrogen, phosphorus, and potassium—varies as does their efficiency of utilization of these elements.

Each of the important tropical grasses has sufficient drought resistance to ensure persistence in the ecological niches to which it is adapted. This is essential in much of the Australian tropics with its variable climate and dry winters. Buffel grass with 60 percent of the plant as roots (21) is an example of a species with very high drought resistance. Since none of the grasses grown in the cooler area of the Australian subtropics and tropics has frost-tolerant leafage, rapid deterioration of standing pasture from frosting is not unusual in winter.

Grass Improvement

MUCH of the improvement in tropical grasses has been attained through selection of better ecotypes from introduced material. For a number of years Bogdan (5) has been active in Kenya assembling ecotypes of promising indigenous African grasses and has been most successful in selecting superior lines for use in pastures. Similar work has been in progress in Australia. A number of introduced ecotypes have been commercialized as cultivars in several grasses, notably Rhodes, buffel, *Setaria*, and *Paspalum*. In buffel grass we have nine main cultivars, which is too many. It is better to select relatively few superior cultivars with wide adaptability than to have a multiplicity of types with limited application.

Selection of frost-tolerant ecotypes for cooler areas has proved difficult. However, in *Paspalum*, *P. guenoarum* and *P. rojassi* have promise for frost-labile areas and *Digitaria macroglossa* is much more cold tolerant than Pangola grass. Oakes and Langford (37) found differential cold tolerance in 13 *Digitaria* species grown in both Georgia and Florida with *D. smutsii* and *D. valida* showing considerable cold tolerance. Frost-tolerant ecotypes of *S. sphacelata* were found at high altitudes in the Aberdare Range area of Kenya as a result of special collections by R. J. Jones of the C.S.I.R.O. Division of Tropical Pastures.

In the past there has been a tendency to select grasses for vigor and dry-matter yield rather than for feeding value and compatibility with legumes. To raise the quality of tropical pastures, we perhaps should be selecting grasses which offer only moderate competition and allow an increased proportion of legume in the pasture. Sheep have been used in Australia to attempt selection of lines with higher intake and digestibility in introductions of grasses like Rhodes, buffel, and *Setaria*. This has not differentiated any higher quality lines in these grasses as yet, because the number of lines which can be examined in this way is necessarily limited. An *in vitro* digestibility method closely agreeing with *in vivo* has now been developed for tropical grasses. Large numbers of introductions are now screened to locate the few promising enough to study in animal intake and digestibility trials. Preliminary results are encouraging and it is hoped to gradually replace the main grasses with similar cultivars of

higher feeding value. The need to select lines on the basis of feeding value becomes still more vital in situations where fertilizer nitrogen is used instead of legumes.

Progress in selecting grasses for all important characters previously outlined can be speeded up where variation can be increased by crossing. At the Division of Tropical Pastures, breeding work is being done with the cross-pollinating *Setaria sphacelata* and *Sorghum alnum* and the apomictic buffel grass. A high proportion of the main grasses including *P. maximum* types, *Brachiarias*, *Molasses*, *Paspalums*, buffels, *Urochloas*, and the native *H. contortus* are obligate apomicts. Fortunately apomicts produce some functional pollen so crosses are possible if sexual types can be found. Up to the present these are available only in buffel grass (4) and *Paspalum* (11). In our work with buffel grass, the sexual blue buffel line from Texas has been crossed with Australian apomictic cultivars, and this has generated a wide range of variation which exceeds that in all the introduced material. It is now possible to combine cold tolerance, higher feeding value, and better compatibility with legumes in new lines of buffel more closely adapted to the Australian tropics.

Setaria sphacelata comprises an autopolyploid series with a basic chromosome number of $x=9$ and contains diploid, tetraploid, hexaploid, octoploid, and decaploid races (15). Crosses can be obtained between all proximate ploidy levels except diploid and tetraploid and between some high and low levels (16); therefore, lines of *S. sphacelata* for seed should not be grown adjacent to each other. The current cultivars Nandi and Kazungula are diploid and tetraploid, respectively, but lack frost tolerance and have moderate feeding value. Crosses have been made mainly at the tetraploid level between Kazungula types and frost-tolerant Kenya introductions to obtain bred lines combining the desired characters with an extended growth period.

Sorghum alnum, a tall, short-lived perennial, is valuable as a pioneer grass on the newly cleared fertile brigalow areas of Queensland. It is compatible with the winter-active alfalfa because it is a summer grower with somewhat open leafage. The main cultivar Crooble was crossed with perennial sweet sudan grass. Lines with higher yield and persistence, greater tolerance to leaf diseases, and with

brown glumes and juicy stems have been produced. The last two characters were linked and inherited tetrasomically (38). Selection was facilitated because of an association between translucent mid-rib, juicy stem, and high sugar content.

In view of the increasing importance of Pangola grass and its susceptibility to a virus (14), which is gradually spreading around the tropics, there is a need to resynthesise a range of lines similar to it. One approach would be to double the chromosomes of Pangola grass (39) and then cross with a sexual hexaploid *Digitaria* species. It should then be possible to select lines with greater cold and virus resistance and with a higher protein level and other desirable characters.

Animal Production

YOUNGE *et al.* (45) have shown that in the Maui tropical wetlands of Hawaii, fertilized *D. intortum*-Pangola grass pastures will give profitable annual live-weight gains per acre of around 700 lb. with Hereford steers. They state that about one quarter of the Hawaiian rangelands, which are now unproductive, are capable of comparable production with this pasture. There is little doubt that fertilized pastures based on legumes like *D. intortum* and Centro could make a significant impact on animal production in similar wet tropical areas in other countries.

The tree, *Leucaena*, is another legume which has given good results in Hawaii. On the Kona coast of Hawaii and on the Kauai coast, *Leucaena* is grown on decomposing lava with Guinea grass, and gives annual live-weight gains around 600 lb. per acre. The potential of *Leucaena* is neglected in many countries, even though it is often present either as a native or chance introduction. The island of St. Croix off Puerto Rico is one area where *Leucaena* has given high producing pastures in association with Pangola grass. In the Australian tropics we are beginning to realize the possibilities inherent in *Leucaena*-based pastures. Cattle live-weight gains on *Leucaena*-Pangola grass pastures, under the right environment, could well match those from nitrogen-fertilized Pangola grass.

Davies and Eyles (13) have estimated that northern Australia has an untapped resource of 260 million acres which can be developed with pastures

and carry 60 million cattle—a seven-fold increase over present numbers. Much of this area is dry tropics and sub-tropics with soils deficient in phosphorus, sulphur, and molybdenum as well as nitrogen. Development is now being achieved with the application of molybdenized superphosphate and use of legumes like Townsville lucerne and Siratro in the drier areas and Greenleaf *Desmodium* and *Leucaena* in moister coastal areas.

Research results to date show that Townsville lucerne will undoubtedly have a decided impact on beef production in northern Australia, particularly north of the Tropic. Shaw's work (41) at Rodd's Bay, Central Queensland, showed the potential value of including Townsville lucerne with native Spear grass and making annual applications of 1 cwt molybdenized superphosphate per acre. Year-round carrying capacity on 9 acres increased from 1 to 3 steers; live-weight gains per acre increased 5 times to around 150 lbs., and steers could be marketed 1 to 2 years earlier than those from unimproved native pasture.

Supplementary pastures of the perennials Siratro or *Leucaena* with sown grasses like Rhodes, buffel, and *Setaria* are being increasingly used and are also giving substantial increases in stocking rate and live-weight gains per acre compared with native pasture. As a result of 't Mannetje's work (29) in southeastern Queensland, a pasture of Rhodes grass or buffel grass and the legumes Siratro and alfalfa is proving to have potential south of the Tropic. Alfalfa, being a winter and spring grower, complements the summer-growing grasses and Siratro so that pasture-feeding value and animal live-weight gains are less variable throughout the year.

Conclusions

Research to date has produced a range of promising adaptable tropical legumes and grasses and has identified soil mineral deficiencies restricting pasture growth and beef production in northern Australia. The techniques and species developed can be used with confidence to markedly increase production from grazing ruminants under extensive conditions, not only in Australia but also in many tropical areas overseas. Tropical pasture plants with major potential include the legumes Centro, Stylo, Townsville lucerne, Siratro, Greenleaf *Desmodium*

and Peru Leucaena, and the grasses Guinea, Pangola, Setaria, Green Panic, Rhodes, and Buffel. Those more restricted in application due to soil, climate, and management requirements include the legumes Puero, Glycine, Silverleaf Desmodium, Miles Lotononis, Dolichos and Vigna species and the grasses elephant, Brachiarias, kikuyu, molasses, Paspalums and *Sorghum almum*. There is a need to continually adapt all these plants more closely to the pasture environment by introduction and breeding.

A number of important problems still remain to be solved. For example, what are the best legume-grass combinations and management and fertilizer practices to ensure legume persistence and a continuous supply of high quality pasture throughout the year for the grazing animal? Does differential grazing affect persistence of any of the pasture components, particularly legumes? Do the nutrient levels sufficient for optimum dry matter and protein production in the various pasture plants fully supply the needs of the animal, particularly the breeder?

In many areas, tropical legumes are the cheapest and easiest way to provide pasture nitrogen, but there is still a distinct need for further research on the factors affecting efficiency of their rhizobium symbiosis when they are grown in contrasting environments. Soil type can affect nodulation and legume growth. Also, what is the fate of elite rhizobium strains applied to legume seed at planting, which opens up a whole new field of rhizobium ecology?

The respective roles of legumes and fertilizers in providing pasture nitrogen and protein should be considered relative to the climate and degree of sophistication of agriculture in the region. Use of nitrogen-fertilized grass without thought of the costs involved has tended to be the first line of approach to pasture production in developing tropical countries. Many tropical grasses have low feeding value, so evaluation of their nitrogen response should be in terms of total digestible nutrients and not dry-

matter production. Profitable production from nitrogen fertilized grass requires use of a high quality grass like Pangola, heavy supplementary dressings of phosphate and potassic fertilizers, and a high rainfall or quantities of cheap irrigation water. A high stocking rate and superior management are also essential to efficiently use the bulk of dry matter produced with nitrogen.

Whether pastures are legume based or not, we do not know what proportion is actually eaten by grazing animals. Much of the dry matter and protein produced is wasted. Efficiency of conversion of our improved pastures into meat is far too low and is our most important problem. Does the solution lie in increasing their legume content since animal intake of digestible protein and energy is much higher for tropical legumes than tropical grasses at most stages of growth? These differences, particularly in digestible energy intake, require further research.

Another important factor needing attention is the effect of introducing a high proportion of genes from the Brahman and Afrikaner into the cattle population, as these breeds digest dry matter better than British cattle under tropical conditions. In crosses they also confer a high level of tick resistance, which reduces costs of beef production and lessens the problem of tick strains resistant to a range of tickicides.

To find how to get the best out of our tropical pastures, the ecosystem approach is needed. In this approach, selected pastures are established in the main ecological zones, and all important parameters associated with soil, pasture, and animal are measured and their interactions studied with the aid of the computer. The factors restricting beef production can then be identified.

In view of the concentration on tropical pasture research in Queensland, it is appropriate that the venue for the forthcoming Eleventh International Grassland Congress in 1970 should be near Brisbane. Perhaps solutions to many of the problems discussed will be suggested by colleagues from overseas.

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*Hier elemente, innig gesellt,
bilden das leben bauen die welt.*

Goethe

SOIL BIODYNAMICS and ECOSYSTEM EVALUATION

F. W. PAULI

THE scientific revolution which began with the discoveries of Galileo and Copernicus and continued until after Newton's death brought, for the first time, a real conviction that the laws of Nature cannot only be understood by man, but also be effectively used for his practical gain.

Our society, dominated by science and technology, sets an overriding value on the search for truth, defined not merely as that which makes a series of propositions intellectually satisfying, but ultimately as the faithful description of our natural and swiftly changing world.

One of the most characteristic features of the modern advances in science is the increasing interest in the boundary fields between the individual sciences. This is particularly true for the science of the soil, being an offspring of geology, physics, chemistry, and biology. In common with all other sciences, it deals with the movements and changing configurations of matter and with the accompanying transformation of energy.

The Place of Soil in Nature

Soil scientists are so busy solving ad hoc problems, that there is little time left to formulate general principles.

G.V. Jacks, 1954

SINCE soil may be regarded as a natural body derived from certain mineral parent material and organic residues, the science of the soil occupies an intermediate position between the sciences of animate and inanimate nature. It synthesizes the findings of a number of natural sciences, the pedosphere (soil) being the resultant of the interactions between lithosphere, hydrosphere, atmosphere and biosphere. Soil must be regarded as a "flowing" or an "open" system.

In the upper lithosphere numerous geochemical processes take place. All matter in the earth's uppermost surface layer participates in a slow, rather complicated migration which causes pronounced changes in the structure and chemical composition

of rocks. Unlike the closed endogenic cycle of matter occurring at deeper levels of the earth's crust, the exogenic or minor cycle taking place on the surface of the earth is largely open and works essentially in one direction. Under the direct influence of hydrospheric and atmospheric agents, this cycle is of great importance in the manner of occurrence and distribution of minerals in the outer surface of the earth due to its role as a separating and concentrating agent for a number of elements.

The lithosphere is partly covered by a water blanket called the hydrosphere. The proportion of the different kinds of water changes continually, depending on the prevailing thermodynamic circumstances. Thus, gaseous, liquid, and solid water coexist at all times, and there is a perpetual cycle of water, consisting of evaporation, precipitation, and drainage. Substances of the dissolved lithosphere participate as hydrosols in this cycle and migrate into the hydrosphere and ultimately are deposited in the sea.

The atmosphere—the outermost ingredient of the pedosphere—consists of a mixture of gases and vapors. It is in contact with the lithosphere and hydrosphere, and water vapor and air penetrate the spaces between the particles of the lithosphere. Consequently, the atmospheric phenomena in the convection region, or troposphere, which determine climate and microclimate, play a large part in the disintegration of rocks and minerals.

The biosphere—that area of the earth capable of sustaining life—includes plants, animals and micro-organisms and occupies the lower part of the troposphere, probably the whole hydrosphere, and a thin layer of the lithosphere. In spite of the negligible mass of the biosphere as compared with the lithosphere and hydrosphere, its activity is remarkable; its soil-forming effect is important and its influence on the dynamics of soil is decisive. Heterotrophic micro-organisms in the biosphere produce large amounts of organic acids. Biochemical processes participate considerably in the creation of oxidizing or reducing environments; they may even dominate therein. Numerous microbial metabolites and plant-derived bio-colloids set free by microbial activity have chelating and sequestering properties. Humic substances with their unique chemical configuration are the most versatile agents in the terrestrial and freshwater bio-cycle, but probably also in the marine

bio-cycle. Recognition of the importance of these recent developments in theoretical bio-geochemistry—these peculiar bio-colloids—will, in the future, draw more attention from all scientists, especially soil researchers.

There is no sharp boundary between the undecomposed rocks, weathered rock, soil material, and soil. The distinction between soil and environment does not exist in Nature. Consequently, physical, chemical, and biological processes are all active and cooperative in the formation of a soil. Such biophysical and biochemical processes comprise numerous interactions between amorphous and colloidal material of organic and inorganic origin.

In a temperate humid climate, the uncultivated soil usually consists of a thin layer of plant remains, underlaid by a layer of mineral matter and organic material called the topsoil. Humic substances and other organic compounds synthesized by the micro-organisms and dissolved in rainwater have leached out these soils to a great extent, leaving behind an “eluvial” horizon. Metal compounds, dissolved silica, and organic colloids are deposited again in the lower or “accumulation” horizon. But readily soluble salts of Na, Ca, Mg, colloidal silica, and water-soluble humus-metal chelates are removed by the groundwater.

In dry lands with low rainfall, high temperature, and considerable evapotranspiration, leaching is normally negligible. Plant and animal remains are rapidly catabolized, but chemical weathering of mineral matter is rather slow.

In subtropical and tropical regions the soil is mainly the result of intense weathering during which abundant rain has removed most of the products formed. Consequently, very little material is deposited in the horizon of accumulation. The weathered zone may be as much as 25 m thick. Micro-organisms under favorable hydrothermic conditions rapidly mineralize the plant and animal remains, and very little humic material is synthesized. Low-molecular humic compounds in *statu nascendi* bring cations into solution by sequestration, a characteristic process during “laterization” in which alumina and iron oxide (hematite) increase.

In the cold and humid climate with little evapotranspiration for the greatest part of the year, a regolith cover is formed by mechanical or chemical

means. The abundance of surface moisture, in association with polyphenolic lignin-degradation products, quinone-like humus precursors and aggressive microbial metabolites—all produce intensive leaching. In fact, the cold and wet regions are the earth's principal zones of podzol development. Vast stretches of land in these areas lack sufficient drainage, leading to anaerobic soil conditions. Gleyzation is the consequence of prolonged waterlogging with sticky, compact, and structureless soils of low biodynamical behavior.

The soil is nearly always in a state of development. With the passage of time, it develops fairly distinct horizons, the cross-section of which is known as the soil profile. The degree of profile development depends on the intensity and duration of activity of the different soil-forming factors under conditions given. The local profile is the outcome of such activities, although it is not necessarily an end-product.

Soils which embody the effects of all the forces working together on parent material—mineral as well as organic—over long periods under normal conditions are normal or “zonal” soils. In certain soils, water may have a disproportionate effect. Such soils are called “hydromorphic” and belong to the “intrazonal” soil types, of which gley- and groundwater soils are typical representatives. Soils which have few or no morphological characteristics and thus resemble their inorganic parent material are called “azonal.” Fresh alluvium and aeolian sands are the principal examples of this soil group. Strictly speaking, the term “soil” should not be applied at all to such materials as they have not been exposed long enough to soil-forming factors, and no thorough mixing of the different soil components has taken place.

Soils belonging to the transition areas between semi-arid and sub-humid zones represent the majority of our agricultural lands. The brown and black soils which were formerly steppe soils are the oldest agricultural lands. After the fertile areas ceased to provide enough agricultural products, the less favorable savannah and forest soils were cultivated. Farming is now constantly spreading into less suitable stretches of land.

The more drastic the climatic conditions, the more extreme are the soil types and the more difficult and complicated will be man's method of cor-

recting and improving the dynamics of these sensitive soils for agricultural and silvicultural purposes.

Fundamentals of Soil Fertility

A scientist need not apologize for choosing soil as an interesting object in itself.

G. W. Leeper, 1965

THE soil, unlike its mineral starting material, has fertility—a dynamic property for carrying plants. With the edaphon—the soil flora and fauna—plants convert their habitat into inorganic material by emitting energy into it. Soil fertility, therefore, is a manifestation and measure of the success of vegetation and soil organisms in reaching a high standard of living. The same condition is reflected in the structure of a soil.

Whereas in unfertile soils, structure is mainly the result of abiotic processes (cementing discrete particles by iron and aluminium hydroxides) in fertile soils it is chiefly the consequence of biotic processes (shaping and aggregating of clusters). Although micro-organisms synthesize these aggregating agents and some of these binding substances are derived from plant cell-wall material, all the members of the macrobial edaphon shape the crumbs, cracks, crevices, and pores which characterize the visible soil structure.

The role of grass roots in binding and compressing soil particles and penetrating the soil mass—in conjunction with the humic substances, clay colloids and clay-humus complexes—is essential in the formation of the typical grassland crumb-structure, also known as “Krumelverband.” Larger and smaller roots than those of grasses act similarly. But the graminaceous plants, by their peculiar anatomical disposition of endodermis and exodermis in the root system as well as the decomposition products hereof, are particularly effective. Soil fertility, therefore, feeds on itself. The same is true for the other great ecological world, the forest soils, where members of the meso-, macro- and megafauna are the major structure-builders.

Soil fertility must therefore be regarded as a biophysical phenomenon. It concerns the transformation of energy in living organisms—essentially the transformation in plants of heat and light into chemical energy—which is returned to the soil to provide energy for the complex edaphon to live and work

and so to construct a habitat. Life on our planet is dependent upon this cycle in the biosphere.

The Biodynamics of Soil

The fact that the worst-fed people live mainly in the drastic climatic regions of our globe is not an accident, but the result of agricultural ignorance.

S. Larsen, 1966

AGRONOMY and forestry are both applied plant ecology, because their aim is the manipulation of organisms for the maximum benefit of mankind. Although plants claim our primary interest, we cannot separate them from their specific environment, especially soil, with which they form one physical system. A forest stand or any other plant community, including any agricultural plant association, is an aggregate or grouping, based on area, and is the botanical component of the ecosystem.

The ecosystem concept in applied plant ecology has been steadily finding recognition in recent years, and the term appears more and more frequently in biological literature. Although the organism complex with the habitat factors and conditions is commonly accepted in forestry, its implications in agronomy have not been recognized to the same extent.

Since plants are a part of the biotic factor in soil processes, and each is so intimately a part of the other's environment, it is logical to include soil as a component of the ecosystem rather than regarding it as an independent body. Indeed, the parallelism between some of the concepts in pedology and phytosociology is striking evidence of this close relationship between plant and soil. If vegetation and site are interrelated parts of a greater entity, then neither stands alone. Some phytosociologists and pedologists have already recognized that the vegetation-soil system is a dynamic unit and reacts as a whole. The interactions between vegetation and specific environmental factors and conditions have sometimes been discussed in a quantitative manner, based on the hypothesis that if soil and vegetation develop simultaneously in response to the same factors and conditions, there must be also a correlation between them.

Although the degree of correlation between kind of soil and plant community has long been a debatable issue, field evaluations in connection with

soil surveys are indicating that such relationships do exist. The usual view is that the culmination in development of soil or vegetation is an apparently permanent condition, reached when both are in equilibrium with all incident agents, especially climate. But environment is never in a static equilibrium. A variety of changes goes on continuously, and a number of them even result from the soil-forming process itself.

In its fundamental aspects, an ecosystem involves the circulation, transformation, and accumulation of energy through the medium of living things and their activities (photosynthesis and decomposition), but also in the anthropogenic ecosystem through all kinds of cropping (herbivory, crop removal, deforestation, etc.). Since the soil system must have energy for its operation, the rate of most soil reactions is proportional to the intensity of the driving forces. That is the reason for the failure of the simple "soil-zonality" principle, which overemphasizes the climatic effect and leaves out the vegetation to a large extent. On the other hand, vegetation alone can hardly be used to indicate the performance of the ecosystem, since within such a dynamic system plants and soils are mutually dependent.

Processes rather than external forces and conditions should serve as criteria for ecosystem evaluation. This concept stresses the dynamic equilibrium of the plant-soil system in its environment.

Human activity finds a proper place in applied plant ecology by forming new ecosystems. Although the agents initiating such ecosystems are directed or controlled, the essential interrelationships between vegetation and soil remain the same. That makes any natural or anthropogenic ecosystem suited for practical studies on how plant and soil influence each other under prevailing environmental conditions.

All the processes operative and interacting in the soil under a certain plant community are reflected in the amount and character of the humus formed. Synthesis of humus depends largely on the biochemical activity of all soil organisms and on the physio-chemical processes such as condensation and polymerization which, in turn, are influenced and governed by the other soil-forming agents. Moreover, humic compounds undergo continuous changes—multiplications as well as diminutions—during which profound rearrangements in their



molecules take place, resulting in a great diversity of their chemical, physio-chemical and biological properties. Logically, determinations of humus level and composition isolated from soil provide valuable genetic information and clues as to how vegetation and soil influence each other.

The major part of the total reaction in soil during mineralization and humification of organic residues depends on the activity of soil micro-organisms with their enzyme systems. They perform and exercise many biochemical functions; the soil may be regarded, therefore, as a gigantic biochemical laboratory.

No weathering of inorganic materials and no degradation of organic residues take place in any medium where oxidation-reduction processes are not playing a very decisive role. As in all other biological systems, the soil has a characteristic "Grenz potential," brought about by a mixture of compounds in oxidized or reduced state. Apart from the influence of dissolved salts and clay minerals, organic residues, microbial metabolites and humic compounds operate as electron donors, rendering their environment a reducing one.

On the other hand, micro-organisms are capable of installing their own environmental redox potential at which they have optimal metabolic conditions. Texture and depth of soil above a free-water surface regulate the oxygen diffusion rate. Micro-pedologically speaking, soils are not homogenous horizontally as well as vertically, even in the arable layer that is thoroughly mixed. This heterogeneity of the potential is closely related to the biodynamics of soil since practically all processes in soil are controlled by this physio-chemical criterion.

Consequently, the study of microbial activity in soil offers the possibility to interpret the dynamics of the soil-plant system. Fluctuations of macro- and microclimate, determining the hydrothermic conditions in the upper layer of a given soil type with an unfaltering topography under a certain plant community (natural or anthropogenic climax)—these are the ruling parameters for the biological processes in soil.

Since all these phenomena undergo continual alterations, evaluation of ecosystems in a biodynamical way seems justified. Methods and techniques for the appraisal of soil biodynamics are as follows:

a. Mechanical analysis and aggregation studies of soil.

b. Determination of the hydrothermic conditions, including evapotranspiration.

c. Potentiometric measurement of the oxidation-reduction level.

d. Primary and secondary fluorescence microscopical observation of inorganic, organic and living components of soil.

e. Determination of the biological activity in soil by microrespirometry (Warburg-Technique), enzyme tests and membrane-filter isolation of physiological groups of micro-organisms.

f. Characterization of humic compounds:

1. Amounts by acriflavine adsorption (fluorimetry).

2. Quality by optical density (spectrophotometry).

g. Gas composition and exchange in soil (gas-chromatography). Other useful and reliable techniques can be easily adapted to such studies, depending in what direction the whole experiment is laid out.

Even though the results obtained during such an appraisal do not represent absolute values, considered together they may provide new information to characterize the performance of natural and anthropogenic ecosystems in forestry and agronomy. This knowledge, combined with certain analytical data of conventional soil and vegetation evaluations, will help to (a) make the best use of natural ecosystems, (b) facilitate their management for maximum productivity, and (c) conserve natural wealth.

Dynamic Programming in Ecosystem Evaluation

The proof of general systems hypotheses is in their empirical evaluation. But their findings are important, crucial in the development of general theory about living systems.

J. G. Miller, 1965

THE multiplication and propagation of the human species, and its elaboration of technology, have increasingly influenced the natural ecosystem. Man is tool-maker, refuse-accumulator, and manipulator of ecosystem. Hence, modern man with his technology has the power either to preserve or to accelerate a decline of natural ecosystem. Such an ecosystem can be regarded as a predetermined dynamic unit which, like a clockwork mechanism, is

either performing or running down. Altogether, therefore, the anthropogenic ecosystem can be described as an open system in which various practices in management are carried out by man in the course of his endeavor to provide a favorable environment for life. A single agricultural or silvicultural program is beneficial or detrimental to ecosystem.

The removal through harvesting of more nutrients than are replaced and the disturbance of the biological equilibrium of soil are certainly forms of ecosystem exploitation. Anthropogenic accumulation of such toxic materials as biocides, sewage effluents, excessive amounts of nitrate fertilizers and microelements are noticeably affecting the ecosystem.

On the other hand, man can also rejuvenate the ecosystem by improving and reclaiming the plant-soil system. He witnesses—and more and more arranges—a competition between organizing and disorganizing forces, and has it in his power to see that the forces of organization predominate in his ecosystem. He can plan activities in the biosphere to make both the conservation and development of optimum ecosystem real and enduring possibilities. In one manner of speaking, this is the real vocation of the ecologist, forester, and agronomist.

A deep understanding of Nature can result only from a knowledge of the many separate and highly differentiated entities that characterize any natural or artificial system. This integrated approach is the one that the classical Greeks assumed to be the true form of knowledge.

What is the best scientific approach for such an evaluation of the ecosystem? I suggest the methods of cybernetics. Cybernetics is a science concerned with patterns of control, whether of living or non-living systems. The same laws apply to both biological systems and mechanical structures. No organism, however, is perfectly static. Life always maintains a dynamic and therefore fluctuating equilibrium between opposing tendencies. Stability in the biological sense is that of an oscillating system.

The laws of cybernetics are not statistical laws but appear to be a new type of calculus, within whose framework even the unpredictable behavior of living systems can to some extent be categorized. Its principal service to the research of ecosystems and soil biodynamics may only be to unify certain concepts that hitherto have proved somewhat intract-

able. The innumerable combinations that could exist obviously cannot all be computed. But a functional, factorial method will probably achieve most by stimulating new questions and new orientations for ideas, and by providing reliable information on the trend of ecosystem development under certain conditions. This approach involves numerous assumptions, and is not therefore entirely free from subjectivity.

The advent of computers has made it possible to deal with complex problems which before were virtually insolvable. These problems fall into two broad classes. The first one consists of those problems where the mathematical aspects have been solved, and the prime difficulty is the physical one of dealing with vast amounts of data. In the second, the computer is used to simulate the actual system; for example, to simulate the nervous system of a living organism or the fluctuations over a period of time of an insect pest population affected by predators, parasites, weather, or insecticide applications.

Our present knowledge of the problem of the

complex dynamic biomass of the soil-plant system must fall into this second category. We have not as yet reached the stage of even considering solving the problem by use of computers. There is still much work to be done on the interrelationships between the different variables involved in the ecosystem, so that the problem can be reduced to mathematical terms.

In spite of this obvious inherent difference between the two types of systems, there are many basic similarities. In a mechanical as in a biological system, we have feedback control—a type of see-saw arrangement. The pattern of control in both systems is often one of degree of magnitude.

As our understanding of the system increases and as we are able to specify the effects on the systems of various factors, we are able to control ecosystem-management procedures. We may, for example, be able to use the technique of programming information about a dynamic state to assist us in making decisions about such factors. But a great deal of difficult work still remains to be done before we reach that stage.

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THE EXPANDING ROLE OF AGRICULTURAL ECONOMICS

GLENN R. SMITH



AGRICULTURAL economics, a unique product of the land-grant college—USDA research establishment, is an integrating science carrying an important and expanding role in agricultural and rural-life research programs. Yet the heritage and characteristics of agricultural economics might be better understood by those in associated disciplines. It is hoped that this paper will contribute to such an understanding, because much of the work of the economist—as an integrating scientist—has wide application in the findings of many disciplines. Scientists have always had much in common, and it is unfortunate that intense interest in subject matter and other factors often hinders communication between disciplines and thwarts appreciation of the total research program.

Scope of the Challenge

TODAY the State station—USDA research establishment is faced with an unprecedented number of problems of increasing complexity. Some of the problems of the rural community are spilling over

into other areas. The city ghetto, for example, has developed partly as a result of the decline in employment opportunities in certain rural areas. Economic problems become intermingled with social problems; the interdisciplinary approach has taken on even greater significance. Because of the growing involvement of people—masses of them—demands for solutions to the problems will become more pressing. Thus, the challenge to the State-USDA research establishment has never been greater.

Research activity is no longer restricted to the task of finding and suggesting ways to produce agricultural products more efficiently, although this will remain an important function. The broad problems facing agriculture today invariably carry economic implications that cannot be ignored. Economy of scale, management factors, motivation, demand, and resource use—all these terms and more have become commonplace in the integrated pattern of modern agricultural science. Moreover, we cannot overlook the rising importance of that distinctly 20th century phenomenon—agribusiness. The real

potential of agribusiness is at least partly reflected in the increased student enrollment in agribusiness curricula. In many colleges of agriculture, enrollments are increasing much more rapidly than for other courses of study. How well are we teaching these future agribusiness leaders so that they will be well equipped for the tough decision-making they will ultimately face? Research could provide some of the needed techniques and resource material.

A Young, Vigorous Science

ECONOMICS is one of the oldest disciplines, but agricultural economics is distinctly a product of the 20th century.¹ Its rapid growth in this country has been exceeded only by the demands made upon it. The ground to be covered is ever widening, and the tempo is quickening.

Agricultural economics received a big boost with the passage of the Purnell Act of 1925 which provided that "The funds appropriated pursuant to this Act shall be applied only to paying the necessary expenses of conducting investigations or making experiments bearing directly on the production, manufacture, preparation, use, distribution, and marketing of agricultural products and including such scientific research as have for their purpose the establishment and maintenance of a permanent and efficient agricultural industry, and such economic and sociological investigations as have for their purpose the development and improvement of the rural home and rural life, and for printing and disseminating the results of said researchers."²

The commingling of thoughts and ideas of men whose early training was in different disciplines—heterosis, if you please—gave breadth and depth to their effort. If we look at the academic genesis of the first agricultural economists, we find that H. C. Taylor, H. B. Hibbard, and E. G. Nourse were economists who developed a keen interest in the problems of farmers. Dr. W. J. Spillman originally was a plant breeder. G. F. Warren was first trained as a horticulturist, but when it became evident that there were problems for which

the conventional horticulturist didn't have the answer, he became interested in economics and vigorously applied himself to developing knowledge on farm management and forces affecting the farm economy.

The agricultural historian, N. B. S. Gras, characterized the early agricultural economists as "a growing group of scholars in the field of agricultural economics, the intellectual elite of all of those interested in agriculture."³ Among those mentioned by Dr. Gras were G. F. Warren, H. C. Taylor, J. D. Black, J. S. Davis, O. C. Stine, H. B. Hibbard, L. C. Gray, and E. G. Nourse. Dr. Black was a powerful figure in the shaping of agricultural policy during the 1930's and 1940's.

These men and others recognized an understanding of the body of economic knowledge as their first order of business. But their early training was also a part of their body of knowledge, and intramural debate was a continuing process. Dr. Warren's unrelenting insistence that generalizations based upon general observation and logic were hypotheses that must be verified by empirical analysis may have been antagonizing at times to those having neo-classical background, but it resulted in fruitful discussion. Likewise, the "scholarly theorists," as they were sometimes called, kept the empiricists doing their homework on the various schools of economic thought and the development of theoretical concepts. Fortunately, this hybrid vigor continues today. A check on the undergraduate training of contemporary agricultural economists will reveal that many did their work in fields somewhat removed from economics. Intramural and self-evaluation continues to be in order as exemplified by the excellent articles by Kelso and Breimyer.⁴

Characteristics of Agricultural Economics

AN agricultural economist is concerned with both micro and macro analyses. Prediction or estimates

¹ "In a way it is fair to say that economics was the parent of scientific biology, since Darwin acknowledged his basic indebtedness to Malthus for the idea of natural selection."—Boulding, Kenneth E., *The Skills of the Economist*, p. 134, Howard Allen, Inc., Cleveland, Ohio.

² USDA Miscellaneous Publication No. 515, September 1946, p. 14.

³ Gras, Norman Scott Brien, *A History of Agriculture*, p. 441, F. S. Crafts & Co., New York 1940.

⁴ Kelso, Maurice M., "A Critical Appraisal of Agricultural Economics in the Mid-Sixties," *Journal of Farm Economics*, 47:843-857, February 1965. Breimyer, Harold F., "The Stern Test of Objectivity for the Useful Science of Agricultural Economics," *Journal of Agricultural Economics*, 49:339-350, May 1965.

affecting the total economy or portions thereof generally entail macro analysis at some stage. Because the realm of study is often large and sometimes diverse, analyses often need to be much greater than researchers generally are accustomed to planning.

Although communication between researchers is improving, the economist too often tries to be his own sociologist or psychologist for the simple reason there is no one near by, to his knowledge, to whom he can turn for consultation or help.

Since much of the economist's effort is devoted to bringing technical knowledge into a model that will maximize income or achieve desired goals, the close proximity of economists to researchers in other disciplines at the State experiment stations and within USDA has put them in a unique position. Those in other disciplines represented in the State-USDA research establishment share, naturally, in the uniqueness of this position. It has contributed to making U.S. agriculture the envy of the world.

The subject matter of agricultural economics covers a broad spectrum in which many areas of specialization and logical division can be made. The temptation to proliferate into a number of separate departments—as has been the case in some other discipline areas—has been resisted by leading agricultural economists, and probably for good reasons. Many institutions have attempted, or are attempting, to recombine related departments into larger units.

To say that agricultural economics has reached perfection would be to deny that it has potential for further growth and improvement. New knowledge does not simply add to the current body of knowledge. It frequently replaces or modifies past knowledge. A live discipline is a changing one. However, despite the constant flow of new theory and empirically proven principles, a few economists have despaired and a few researchers in other disciplines have belittled attempts to scientifically treat social and economic phenomena. There are those who have gone so far as to argue that economic behavior does not lend itself to scientific treatment, but such notions have not prevented growth in the development of knowledge.

The feeling of hopelessness of some economists probably stems from the fact that as soon as a relationship of man's reaction to a situation is discovered, man begins to use this information in an

effort to modify his actions and thus improve his position. Therefore, economists may envy the position of biological and physical scientists who they assume deal with subjects that don't "talk back." This advantage is more apparent than real. In the first place, it should be emphasized that lack of subject stability is not peculiar to human phenomena. Furthermore, these same economists do not hesitate to use the demand curve, which is, in effect, a "talk-back" curve.

A defensive position is incongruous to a scientist, but a challenge can be stimulating. The continuous challenge to prove that the new born babe—agricultural economics—was a science and deserved such a title served a useful purpose. The youngest child may find the jealousy created by his presence to be painful at times, but he benefits from observing the successes and failures of his older brothers, to say nothing of their prodding.

A reviewer could hardly spend 3 months a year examining the work of researchers in all disciplines at the State agricultural experiment stations—as was formerly done by the Office of Experiment Stations—without observing the absurdity of the "conventional wisdom" in attempting to establish a pecking order of scientific purity by subject-matter areas. All disciplines have their problems. The tendency to confuse subject-matter or even a specific research methodology with science, however, does occur too often.

An Understanding of Scientific Methods

AN aggressive and effective research program is essential for any discipline to be recognized as a science, especially if it is to grow in usefulness. Likewise, an understanding of what constitutes scientific research is obviously a prerequisite for a scientist, irrespective of his subject-matter interest. Social scientists have made progress in developing new and more sophisticated research procedures during the past 2 or 3 decades, which in turn has enabled them to conduct more comprehensive studies.

Much has been said about the experimental method and experimentation. The experimental model or controlled experiment is an excellent tool, but it is by no means the only tool used by the scientist. To assume that this procedure constitutes the "scientific" approach and that all other approaches are nonscientific would obviously be an

error.⁵ Such a definition would leave Einstein largely outside the "hallowed" walls of science.

Whether a scientist is using the controlled experiment or other approaches, he observes, identifies, records, analyzes, and synthesizes. The geologist, astronomer, astrophysicist, economist, sociologist and others who have made tremendous contributions to the knowledge and welfare of man have seldom used what is generally termed the "experimental method." Actually, some major discoveries have been more the result of observation by a discerning mind rather than results derived from an experimentally tested hypothesis. The discovery of the therapeutic value of penicillin is an excellent example.

In testing the hypothesis, the researcher must be alert to observe the unexpected. Ability to distinguish between a statistical deviation and a new lead is a great attribute. Intuition and serendipity may go together.

To summarize, it matters not whether information is obtained from phenomena which occur naturally or made to take place under experimental conditions.⁶ It is the identifying, recording, and analyzing of significant phenomena, and the measuring of actions and interactions that constitute the efforts of the scientists. If one can construct an experiment through which to make observations—well and good. If pertinent knowledge can be obtained without constructing an experimental model, that is also well and good.

Objectivity and Methodology

IF research is the orderly pursuit of knowledge, objectivity is the heart of science. Complete intel-

lectual honesty is essential. Preconceived judgment or presuppositions, even subliminal ones, ought to be avoided. Is this humanly possible? Probably not entirely. But safeguards can be found through scientific sampling, selection of appropriate methodological procedures, and other methods. Along with identification of the problem, selection of the phenomena to be tested, and formulation of hypotheses, another important step must be recognized: the adoption, adaption or development of analytical procedures that will assure accurate testing of hypotheses through measuring and synthesizing the relationship, actions, and interactions that exist. Blind faith in complicated mathematical, analytical procedures—the limitations of which are not thoroughly understood—may lead to some embarrassingly erroneous results.

Recognizing that the effectiveness of a researcher depends largely on the use of appropriate research techniques, the North Central Farm Management Research Committee (NCR-4) agreed to facilitate the preparation of a bibliography listing 10 specific references for each of the various mathematical and analytical procedures that have come into use during the past 3 decades.⁷ Few researchers thoroughly understand the advantages and limitations of all the methodological research tools. But researchers can be found who are sufficiently knowledgeable in the use of any specific methodology to furnish the needed information. The real task is finding the right man for each procedure and inducing him to prepare the desired material. Once the statements are brought together and edited, researchers, graduate students, and research advisors would have a most useful and time-saving source of indispensable information. Furthermore, once this preliminary work is accomplished, someone might be sufficiently inspired to take the second step and prepare a condensed statement summarizing and synthesizing the important aspects of each. It is hoped that the committee will follow through with its stated intentions, because an evaluation of the usefulness and appropriateness of the large array of research tools is long past due. Such action would probably encourage rather than discourage the development of new methodology.

⁵ A research tool or a methodological procedure appropriate for one analysis may be inappropriate for another. Northrop says, "Any specific scientific method is studied in connection with some specific theory and subject matter of a specific science in which its use is appropriate." Northrop, F. S. C., *The Logic of the Sciences and the Humanities*. The World Publishing Company, Cleveland, Ohio, 1947.

⁶ Beveridge, himself a biologist, said in discussing the experimental methods, "Nevertheless, important as experimentation is in most branches of science, it is not appropriate to all types of research. It is not used, for instance, in descriptive biology, observational ecology or in most forms of clinical research in medicine. However, investigations of this type make use of many of the same principles. The main difference is that hypotheses are tested by the collection of information from phenomena which occur naturally instead of those that are made to take place under experimental conditions. Beveridge, W. I. B., *The Art of Scientific Investigation*, p. 13. W. W. Norton & Co., Inc., New York.

⁷ Minutes of Meeting of North Central Farm Management Research Committee (NCR-4) October 26-27, 1964, Chicago, Illinois.

Predictability

DR. Kelso, said, "Science is characterized by an ability to predict real world occurrences with an acceptable degree of warrantability."⁸ Certainly, effective research will yield information that will indicate what will happen or can be made to happen. However, if this definition is viewed in its strictest sense and applied on a broad base, all disciplines would be found wanting.

Beveridge said, "We must remember that, especially in biology, experimental results are, strictly speaking, only valid for the precise conditions under which the experiments were conducted."⁹ The effective agricultural economic researcher strives to make analyses of actual ongoing processes which require much thought on the procedures used. Even so, few perfect and lasting solutions to major complex problems can be cited. When it comes to predicting "real world occurrences," what science has infrequent misses? Have the long range predictions in the real world made by entomologists, pathologists, and others been any more accurate than those of economists? However, let us not forget that the physician, entomologist, pathologist, and economist do have sufficient knowledge and skills to demand a price in the market place. This is true despite the fact that often the patient dies, plant diseases and insects keep less than one jump behind man in his endeavor to produce needed food and fibers, and frequently man finds himself in an uncomfortable financial position. All sciences have a continuing challenge.

Broad scale predictions are not easy to make because the results of any model or methodological procedure will be no more accurate than the accuracy of the coefficients used and the appropriateness of the assumptions made. The development of adequate data and information for analysis may be expensive. Therefore, researchers and research administrators are always confronted with the problem of how to maximize the use of limited resources. They must ask what studies should have first priority. Once a problem is selected, there is the question of how to most effectively proceed with the study.

Once the problem or subject is defined and delineated, there is the matter of identifying phenomena needed to be studied. Specifically, what information or data is needed and how will it be obtained? Is

the problem one that can be solved by a single discipline, or will it require the expertise of many? What is the most appropriate analytical procedure to use?

Too often, the economist, agronomist, engineer, and animal scientist have each tried to go-it-alone, when actually a workable solution for the farmer would require the contributions of each brought together in a model adapted to the farmer's situation. The extension specialist can hardly be expected to put together all the bits of information developed, especially when it is by no means certain that answers to all essential questions are present as is highly unlikely under a go-it-alone practice. In other words, without coordination information gaps may show up.

The recognized need of more research in the social sciences is manifest on many fronts. The late start and modest scale of support of research in the social sciences by the National Science Foundation has prompted support from various quarters to establish a National Social Science Foundation. The Honorable Fred R. Harris, U.S. Senator from Oklahoma, said in support of such a foundation, "What is needed is a distinctive and separate institution within the government for the social sciences, one which possesses a clear political mandate to support imaginative and innovative research and to encourage the development of each discipline in the field, and with sufficient status to represent effectively the needs of the social sciences and to increase their ability to assist the government in dealing with the difficult social problems which confront us." Other suggestions have included the establishment of a National Institute for Advanced Research and Public Policy, an independently endowed institution which would conduct policy-oriented behavioral research.

While it is not the purpose here to evaluate the relative merits of different schemes to provide more support for social science research, it has become abundantly clear that the root causes of economic and social problems cannot be ignored. The land-grant college—USDA research establishment has the base upon which to expand and initiate productive research to provide the solutions to many perplexing social problems. If this is not done, a golden opportunity to grow in usefulness and stature may well be lost to institutions and agencies created to fill the vacuum.

⁸ Op. Cit.

⁹ Op. Cit.



FORUM

HAVE AGRICULTURAL TECHNOLOGISTS OVER-SOLD THEIR SUCCESS?

I FIRST began to wonder about this question somewhere over Illinois on a Chicago-Des Moines flight. Corn was ripening, and from my aisle seat I glanced out the window and remarked that a good crop was assured. My chance seatmate on this flight, an Iowa banker, commented on what a great thing hybrid corn had turned out to be. Then the conversation drifted on to hybrid sorghum and to recent trends in finishing cattle.

He was surprisingly knowledgeable about a wide range of agricultural advances: how high plant population plus heavier fertilization was giving a new boost to yields, how "miracle" rice was helping close the food gap in a number of Asian countries, how high-yielding dwarf wheats from Mexico were showing great promise in India and Pakistan. He thought the discovery of systemic insecticides for the control of the cattle grub was a remarkable research accomplishment.

Then the sum of his views on world-wide agricultural development came forth as we were descending into Des Moines. In essence, he felt that agricultural research had been a great thing, and "now that we have all the technology we need, the remaining job is to educate people everywhere on how to take advantage of it!"

In a state of shock and with dismay that our discussion could not continue, I rented a car and proceeded to my destination on an evening drive through that lush agricultural region so blessed with fertile soil but also blessed with the results of research. Perhaps to one living in Iowa and reading the glowing reports of research successes, it could easily appear that we do have all the technical know-how we need and only have to put it to work.

I began to wonder whether many other people held my seatmate's views. What does the public hear and read about agricultural research? Is the information available to them chiefly from the success stories put out by the experiment stations, the USDA, agribusiness and the foundations? Do they have any opportunity to study objective appraisals of agricultural progress (and lack of it) around the world?

Typical Viewpoints

I AM sure that a professional opinion "pollster" would down-grade my sampling technique. But in the year since that flight to Des Moines, I have steered conversations with a number of persons to the subject of agricultural technology and its relationship to the war on hunger.

Discounting those whose concern for population is confined to last night's jam on the freeway and those whose concern for food ends with the question of "where shall we eat tonight?" I did strike "pay dirt" with eight additional people not connected directly with agriculture. These eight appeared to be educated, widely-read and aware of our current and future world food problems.

Six of the eight tended toward the views of my airplane seatmate: that we have the technology and all we need to do is put it to work. Only two of the eight seemed to comprehend the limitations of our present technology and were fully aware of the need for adaptive research as well as continuing basic studies.

What had these six people read? I concluded that their opinions were based chiefly on news releases and popular magazine articles. Several mentioned the story of miracle rice in *Time* magazine. One referred to the glowing report of Mexican wheats in Asia in the *Farm Quarterly*. Without exception, they were impressed by reports of technical advances but tended to equate progress in one place with world progress and maximum productivity in a most favorable situation with average productivity.

Too Much Success?

HAVE we agricultural technologists over-publicized our success? I think not! It's important for taxpayers and stockholders to know how their investment in agricultural research is paying off. But I am convinced we have under-publicized the progress that must yet be made if widespread hunger is to be avoided in future generations.

To balance each story of a plant breeding success, we should point out the opportunities for the further development of locally adapted varieties and the need for on-going plant breeding programs if we are to keep ahead of ever-changing diseases. When we report some new basic discovery and project its possible utility, we should emphasize the world-wide need for adaptive research in order to put that basic discovery to work wherever it may fit. We must make it clear that technology useful in one soil or climate or social system does not automatically fit another. We must emphasize how little agricultural research has been done in the tropics, the very areas where so many people are reproducing at an excessive rate and the areas from which most of their food must come.

My conversations convinced me that the oft-quoted figures on the ever-decreasing number of farmers it takes to feed the United States population have led people to erroneously equate mechanical progress with increased yields per acre and to assume that all the less-developed countries need is more farm equipment. We must emphasize the importance to high productivity of adapted varieties, good fertilization and effective pest control based on locally developed recommendations. We need to emphasize how imperfect is our knowledge of underground pests and how to control them. Those who project a continuing climb in yields under intensive culture should recognize the increase in soil pests

that often accompanies intensification of cropping, and the research needed if efficient methods of control are to be available in the future.

Improved sources of plant protein have had much publicity in connection with protein shortages in the diets of developing countries. Agricultural leaders should emphasize the importance to future protein supply of the segments of the earth's surface ill-suited to crop production, but nonetheless adaptable to grazing by ruminant animals. We should point up the technical progress that is being made on range and pasture improvement through fertilization and weed and brush control.

Knowledge of better forage utilization through livestock supplementation with non-protein sources of nitrogen as well as minerals has been making great strides. Parallel to these developments is remarkable progress in the control of livestock diseases and parasites that so often limit meat production and raise costs beyond the reach of the masses. Hopefully, the public can be led to realize that more adaptive research is needed to bring about significant increases in the world's capability to convert grass to red meat by using those vast areas of land not suitable for crop production.

Need for Capital

THE fact that technology is only the base on which an efficient agriculture can be built must be emphasized if people are to have a well-rounded picture. They must understand that the farmer, processor, and distributor must have an incentive. They must understand that where the technology is ready and the incentive is there, capital must be available and have its own incentive. Those with whom I talked had little concept of the tremendous amounts of capital required for an expanding agriculture.

"Food from the sea" and "farming the oceans" were topics brought up in several of my discussions. Leaders in agricultural and food technology must help promote better public understanding of the many technical unknowns and the high capital requirements and attendant risks of far-out oceanographic schemes. Fish production can no doubt increase significantly, but past performance suggests the world's fishing industry will require much new technology and new financing if it is to grow faster than population.

The Right Perspective

SEVERAL of those with whom I spoke were much impressed with releases related to research progress in developing new food sources, for example, protein from petroleum. It is our responsibility to help the public keep these interesting new approaches in the right perspective. Giving them every benefit of the doubt as to technical and financial feasibility, it seems probable that most of the world's food will have to come from conventional sources for many decades to come. Hopefully, the public can be shown that promising new food sources are likely to require a high R & D input before fruition, not to mention the high capital requirements for production facilities.

Farm surpluses in the United States and Canada have undoubtedly contributed to the attitude that the research we need is already done. One man stated: "Why should we spend a lot of money on further research when we already have problems of surplus crops?" This is a tough one to answer—whether it is asked by a taxpayer, a legislator, or a public administrator. It's a short-view question requiring a long-view answer. The public, and I think sometimes even agricultural leaders, fail to realize how long it takes to put the results of most research to work.

Current favorable crop reports in India and other countries where famine has recently threatened seem to be dulling the sense of urgency that is needed to insure continuing adaptive research and subsequent development. Some of the improved

food situation is due to the application of new technology, but much more to favorable weather. Outside of Japan and Taiwan, probably no more than 10 per cent of the farmers of Asia have been touched by any phase of modern agricultural technology.

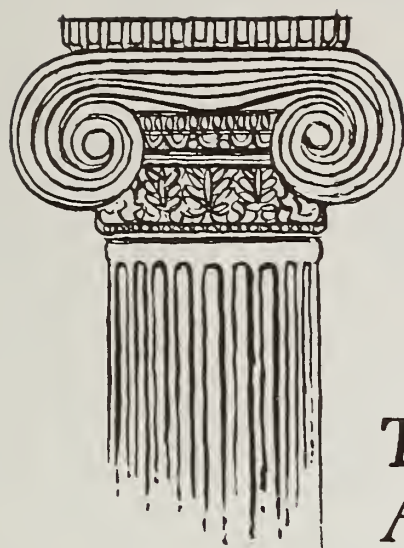
No Choice Left

MOST of all, we should impress people that even with an optimistic view on the future of birth control programs, the world's population is likely to at least double before it can level off. Many demographers think it will more than triple and, of course, some are of the opinion that nothing but mass famine is in store for many of the less-developed countries now experiencing a high rate of growth. Regardless of one's view, it is indisputable that vast increases in food production will be needed in the future.

It's essential for all to understand the importance of a higher level of productivity—based on sound basic and applied research—to the realization of this increased food supply. It is also essential for everyone to understand that the easily farmed land is already in use. The considerable areas of new lands awaiting development, particularly in Africa and South America, will often require new technology for their effective management.

Above all, we must emphasize that the world does not have a choice between increased food production and population control. It must have both.

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